

Latency-Information Theory

The Mathematical-Physical Theory of Communication-Observation

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Abstract—In this paper the mathematical-physical theory of communication-observation that is part of latency-information theory (LIT) is reviewed. LIT surfaced from the confluence of classical information theory, relativity theory, quantum mechanics, statistical physics and a 1978 conjecture by the author of a structural-physical certainty-uncertainty duality for quantized control. Control, radar, physics and biochemistry applications illustrate the theory. As part of the review, LIT is revealed to communicate through latency-certainty channels and/or information-uncertainty channels for observation across latency-certainty sensors and/or information-uncertainty sensors, a mathematical-physical efficiency perspective of the Universe in a four quadrants revolution. While the first and third quadrants are concerned with the life time of physical signal movers and the life space of physical signal retainers, respectively, the second and fourth quadrants are about the intelligence space of mathematical signal sources and the processing time of mathematical signal processors, respectively. The four quadrants of LIT are conjectured to be physically independent with their system design methodologies guided by dualities and performance bounds. Moreover, the tools of statistical physics bridge them, and inherently lead to the discovery of a novel certainty dual for thermodynamics named *linderdynamics*.

Keywords — *latency-certainty, information-uncertainty, mathematical-intelligence, physical-life, communication-channel, observation-sensor, thermodynamics, linderdynamics, biochemistry*

I. INTRODUCTION

The mathematical-physical theory of communication-observation is part of latency-information theory (LIT) [1]. This universal efficiency theory emerged from the confluence of five ideas. They are in chronological order: 1) the certainty advocacy of Albert Einstein of relativity theory; 2) the uncertainty advocacy of Werner Heisenberg of quantum mechanics; 3) the source-entropy and channel-capacity lossless performance bounds of Claude Shannon that guide communication system designs [2]; 4) the thermodynamics-entropy of Steven Hawking for black-holes [3]-[4]; and 5) the 1978 conjecture of a structural-physical certainty/uncertainty duality for quantized control by the author [5].

In this review classical information theory will be designated as mathematical information theory (or MIT) since the units of classical information are mathematical binary digit

(or bit) units. In addition, classical information will be referred as sourced intelligence space (or intel-space in short). This designation will make MIT's fundamental contribution to the emergence of LIT transparent. LIT combines four system design methodologies which are conjectured to be physically independent but that are nevertheless bridged by statistical physics. They are: 1) uncertainty-communications MIT with its intel-space described with bit units and time-communicated through noisy intel-space channels, and where the physical time-dislocations of intel-space exhibit a passing of time Heisenberg information-uncertainty; 2) certainty-observations mathematical latency theory (MLT) with its processing intelligence time (or intel-time) described with binary operator (or bor) units and space-observed across a window-limited intel-time sensor, and where the physical space-dislocations of intel-time exhibit a configuration of space Einstein latency-certainty; 3) uncertainty-observations physical information theory (PIT) with its retention life space (or life-space) described with SI square meter units (specifying the space surface area enclosing the retained signal) and time-observed across a noisy life-space sensor, and where the physical time-dislocations of life-space exhibit a passing of time Heisenberg information-uncertainty; and 4) certainty-communications physical latency theory (PLT) with its motion life time (or life-time) described with SI second units (specifying the time delay of the moved signal) and space-communicated through a multi-path life-time channel, and where the physical space-dislocations of life-time exhibit a configuration of space Einstein latency-certainty. Like MIT, the three other system design methodologies, i.e., MLT, PIT and PLT, have two performance bounds that guide lossless and lossy system designs. Three major dualities are found in LIT. They are: 1) the latency-certainty/information-uncertainty duality that is formed by the two certainty PLT and MLT schemes and the two uncertainty MIT and PIT schemes; 2) the physical-life/mathematical-intelligence duality that is formed by the two physical-life PLT and PIT schemes and the two mathematical-intelligence MIT and MLT schemes; and 3) the communication-channel/observation-sensor duality that is formed by the two communication-channel PLT and MIT schemes and the two observation-sensor PIT and MLT schemes. These three major dualities of LIT are conveniently displayed in Fig. 1, that presents a four quadrants revolution that starts with the PLT of quadrant I, then the MIT of II, then the PIT of III, and finally the MLT of quadrant IV. Also six minor dualities are noted in Fig. 1. They are the two minor PLT/MIT and MLT/PIT dualities of the latency-certainty/

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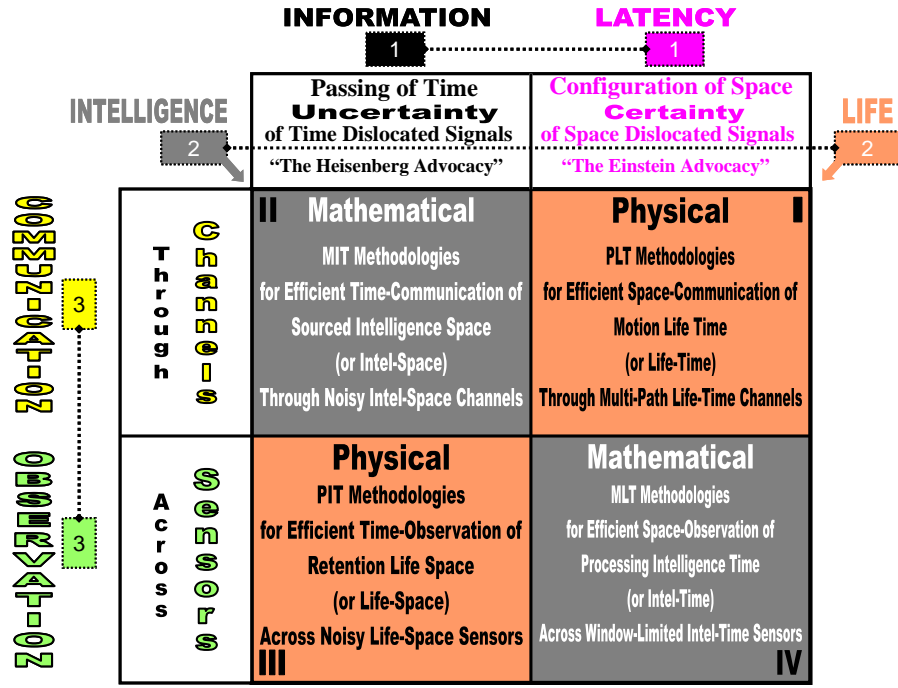


Fig.1 The Latency-Information Theory Revolution

information-uncertainty major duality, then the two minor PLT/PIT and MIT/MLT dualities of the physical-life/mathematical-intelligence major duality and finally the two minor PLT/MLT and MIT/PIT dualities of the communication-channel/observation-sensor major duality.

II. THE LIT CONFLUENCE

The chronological development of LIT is documented next. It starts with the two lossless efficiency performance bounds of MIT that led to the discovery of six others for LIT [6]. Next the conjectured structural-physical certainty/uncertainty duality is explained. Then a 2004-2005 DARPA University Grant for adaptive knowledge-aided radar system designs is discussed that motivated the confluence of MIT with the structural-physical certainty/uncertainty duality conjecture [7]. The section ends with the physical duals for MIT and MLT, i.e., PLT and PIT that were discovered in 2006.

A. The MIT Performance Bounds

The first MIT performance bound is the lower performance bound for source-coder designs, which is called the source-entropy with symbol H in bit units for the sourced intel-space quantity that it represents. H is defined as the expected source-information

$$H = E[I_S(\underline{g}_i)] = \sum_{i=1}^{\Omega} P_S(\underline{g}_i) I_S(\underline{g}_i) = \log_2 \Lambda \quad (1)$$

$$I_S(\underline{g}_i) = \log_2(1/P_S(\underline{g}_i)) \quad \Lambda = 2^{\sum_{i=1}^{\Omega} P_S(\underline{g}_i) I_S(\underline{g}_i)} \quad (2)$$

where: 1) $\underline{G} \in \{\underline{g}_1, \dots, \underline{g}_{\Omega}\}$ is a n -dimensional random vector composed of Ω vector outcomes $\{\underline{g}_1, \dots, \underline{g}_{\Omega}\}$; 2) $I_S(\underline{g}_i)$ is the \underline{g}_i source-information in bit units; 3) $P_S(\underline{g}_i)$ is the \underline{g}_i source-probability; and 4) Λ is viewed as an *effective* number of outcomes, with $\Lambda = \Omega$ for equally likely outcomes.

The second and upper MIT performance bound is for channel and source integrated (CSI) coder designs, see Fig. 2a and [1], [6]. While the CSI-coder's source-coder efficiently compresses intel-space, its channel-coder efficiently uses overhead intel-space for the time-communication of intel-space through a noisy intel-space channel. The CSI-coder's bound is called channel-capacity with symbol C and denotes the maximum percentage of intel-space extracted without loss from a noisy intel-space channel. C is defined by

$$0 \leq C = (H_{\underline{E}} - H_{\underline{E}/\underline{F}})/H_{\underline{E}} \leq 1 \quad (3)$$

where: 1) \underline{E} and \underline{F} are the n -dimensional codeword input and output, respectively, of a memoryless channel (see [1], [6] for further technical details on 'mutual' information); and 2) the conditional source-entropy $H_{\underline{E}/\underline{F}}$ is a *channel-induced intel-space penalty* whose value determines the percentage of the intel-space that can be time-communicated without loss, i.e., its probability of error approaches zero.

B. The Structural-Physical Certainty/Uncertainty Duality

The structural-physical certainty/uncertainty duality conjecture of 1978 gave rise to the mathematically tractable separation of stochastic quantized control designs [8] into a certainty processor-state controller design and an uncertainty processor-state estimator design. In particular, this approach resulted in a Matched-Processors methodology for quantized control [5] which was derived as the certainty dual of the uncertainty Matched-Filters methodology for the detection of transmitted bits through a noisy intel-space channel [9]. More specifically, given observations of the present state of the controlled signal-processor (modeled with deterministic state equations), matched processors evaluated for a suitably small

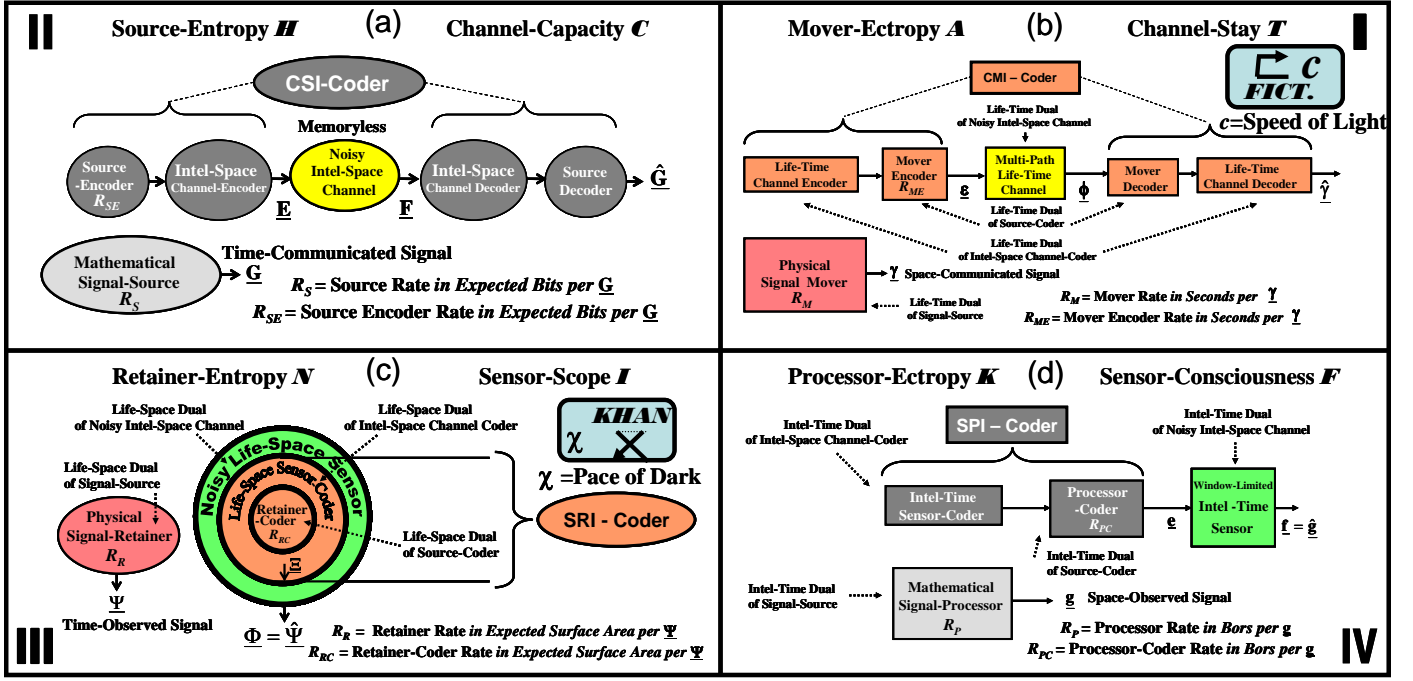


Fig. 2 The Structural-Physical Certainty/Uncertainty Dualities of the LIT Revolution

set of present and future quantized controls the cost to go for each matched control sequence. From these matched processor evaluations the present control was then found that yielded the best cost to go for a suitable horizon, and its value applied to the controlled signal-processor. The approach was repeated as many times as there were control steps. It is of interest to note that besides Matched Processors being rather straight forward, it also has the fundamental advantage of not suffering from ‘the curse of dimensionality’ of the alternative control methodology, i.e., Bellman’s Dynamic-Programming [10].

C. The DARPA University Grant

The merging of MIT with the aforementioned structural-physical certainty/uncertainty duality to produce MLT was motivated by a university grant from DARPA [7]. The objective of this research was to use minimum mean square error predictive-transform (MMSE-PT) source coding [11] for the lossy compression of synthetic aperture radar (SAR) imagery of the earth, later to be used in a knowledge-aided adaptive radar [12] system subjected to severely taxing environmental disturbances. This problem turned out to be extremely difficult to address since in addition to the compression of the SAR imagery, the *processing time* of the associated adaptive airborne moving target indicator (AMTI) radar ‘lossless’ signal-processor also needed to be radically compressed. Moreover, it was also found that regardless of how fast a lossless signal-processor was, it could never be suitably matched to its input when it consisted of compressed SAR imagery that was both radar-blind and highly-lossy. This lack of match between the lossless signal-processor and its compressed input, results in an unsatisfactory signal to interference plus noise ratio (SINR) radar performance.

Fortunately, however, this problem was then solved by once again invoking the Matched Processors structural-physical certainty/uncertainty duality conjecture. In this latest revelation while the compression of intel-space is an uncertainty problem, the compression of intel-time is a certainty one. Moreover and just as importantly, since the certainty Matched Processors methodology was structurally similar to that of the uncertainty Matched Filters methodology, it was felt that the uncertainty-communication MIT system design methodology must also have a ‘certainty signal-processor design methodology’ with dual strategies. In this way MLT inherently surfaced as the certainty-observation dual of uncertainty-communication MIT. Of all the inherited MLT strategies the most compelling one was the appearance of ‘lossy’ processor-coders. After this property was identified it was then applied to the design of a suitably lossy adaptive AMTI radar signal-processor. More specifically, the clutter covariance evaluator whose input was the stored SAR imagery was replaced with a lossy power-centroid clutter processor. This highly lossy clutter covariance evaluator first determined from the stored SAR imagery the power and power-centroid values of the investigated clutter range-bin. Using these values, it then extracted a suitable clutter covariance from a small set, earlier designed off-line and stored in memory. After this approach was tried it was found that besides being extremely fast, the processor resulted in outstanding SINR radar performances while using stored SAR imagery that was both radar-blind and exceedingly lossy. The lossy SAR imagery resulted from the compression of the lossless SAR imagery by a factor of 8,172 [1]. Moreover, an even more surprising result later surfaced [13]. It was that a lossy adaptive AMTI radar signal-processor algorithm can be

designed that emulates the outstanding SINR radar performance of the former scheme without the need of clutter prior-knowledge, i.e., SAR imagery. This highly desirable result surfaced from the discovery that both the range-bin power and its power-centroid can be readily derived from the on-line sample covariance matrix.

D. The MLT Performance Bounds

Similarly to MIT, MLT is found to have two performance bounds for system designs [1], [6]. The first is the lower performance bound for processor-coder designs, which is called processor-ectropy with symbol K and values given in bor units for the processing intel-time levels that it represents. A processor-coder is any replacement of the original signal-processor whose output is said to be lossless when it matches that of the original signal-processor and lossy when it does not. More specifically K is a minimax criterion that is illustrated next with a simple example. This example is of a 1-bit full-adder [14] original signal-processor that has a slow bor multi-level implementation structure where the sum output is associated with six bor levels and the carry-out with five bor levels. The reason for this relatively large number of bor levels is that this full-adder only uses two-input gates. However, for this example it is found that $K=3$ bors since the minimum number of bor levels needed to generate the carry bit is two, and for the sum bit is three as is noted to be the case when a ‘sum of minterms’ implementation methodology is used [14] and more than two-input gates are allowed. While the 1-bit full adder is a lossless processor-coder, a lossy but faster, by one bor level, 1-bit full adder can be readily derived from the lossless case by only implementing the two bor levels for the carry and by setting the sum output to zero. Thus K is defined

$$K = \max[L_p(g_1), \dots, L_p(g_N)] = \max[f_1[C_p(g_1)], \dots, f_N[C_p(g_N)]] \quad (4)$$

where: a) $\mathbf{g}=[g_1, \dots, g_N]$ is the N -dimensional signal-processor vector output; b) $L_p(g_i)$ is the g_i processor-latency, e.g. $L_p(\text{sum})=3$ bors for the full-adder; and c) $f_i[C_p(g_i)]=L_p(g_i)$ conveys $L_p(g_i)$ dependence on g_i processor-constraint $C_p(g_i)$.

The second and upper MLT performance bound is for sensor and processor integrated (SPI) coder designs, see Fig. 2d and [1], [6]. While the SPI-coder’s processor-coder efficiently compresses intel-time, its sensor-coder efficiently uses overhead intel-time for the space-observation of intel-time across a window-limited intel-time sensor. The SPI-coder’s bound is called sensor-consciousness with symbol F and denotes the maximum percentage of the mathematical latency extracted without loss from a window-limited intel-time sensor. F is defined by

$$0 \leq F = (K_{\mathbf{e}} - K_{\mathbf{e}/\mathbf{f}}) / K_{\mathbf{e}} \leq 1 \quad (5)$$

where: 1) \mathbf{e} and \mathbf{f} are N -dimensional vectors that are the input and output, respectively, of a window-limited intel-time sensor (see [1], [6] for further technical details on ‘mutual’ latency); and 2) the conditional processor-ectropy $K_{\mathbf{e}/\mathbf{f}}$ is a *sensor-induced intel-time penalty* whose value determines the percentage of the intel-time that can be space-observed without loss. For instance, if a 1-bit full-adder based recursive adder contributes 2 bor levels of delay for each carry-out, its processor-ectropy is $K_{\mathbf{e}}=16$ bors when it adds 8 bits. Then if

one observes the adder output with a 14-bors window-limited intel-time sensor, the sensor-induced intel-time penalty will be of 2 bor, i.e. $K_{\mathbf{e}/\mathbf{f}}=2$ bors. In turn, this results in the sensor-consciousness value of $F=(16-2)/16=0.88$ informing us that only 88% of the 16 bors intel-time of $K_{\mathbf{e}}$ can be space-observed without loss. Thus the adder intel-time must be of at least 18 bors. The needed 2 bors can be obtained with a sensor-coder that uses prior-knowledge, e.g. that LSBs can be zero, to begin the addition 2 bors earlier in time [1], [6].

E. The PIT and PLT Physical Duals

In 2006 soon after the discovery of the MLT methodology as the certainty dual of the uncertainty MIT methodology, the physical duals for MIT and MLT were also revealed. These physical duals, i.e., PIT for MIT and PLT for MLT, lead to physical system designs that are once again guided by lower and upper performance bounds. Furthermore, the structural-physical certainty/uncertainty duality conjecture for PLT and PIT brings to mind classical themes from physics. The first is the certainty advocacy of Einstein for a perfectly described ‘certainty’ Universe of which his relativity theory was part. Yet it is also well known that the Heisenberg uncertainty principle is at the center of quantum mechanics, which never seems to fail in its description of the real-world for small distances. Thus for many years physicists have been busy in the search for a quantum theory of gravity at the Plank length where it is thought Einstein’s relativity theory yields to quantum mechanics [15]. A recent popular candidate for this theory is string theory with its conjectured eleven dimensions for the Universe as well as further generalizations. Yet, recently [15], experimental data from an exploding star has surfaced conveying a different perspective. This perspective is that the speed of light does not seem to change its value when its wavelength is at the Plank length, with further smaller wavelength results expected in the near future. The results obtained so far have already elicited comments from physicists such as “It would be amazing that in effect we don’t need a quantum theory of gravity,” [15]. Thus it seems that the structural-physical certainty/uncertainty duality conjecture has reasonable support. Retention problems of quantum mechanics may thus be found to form together with the motion problems of relativity theory a true duality where quantum mechanics and relativity theory complement each other and never merge. A desirable outcome of this scenario is that retention problems that are often severely limited in the type of experiments that can be performed, may nevertheless be studied using the structural-physical certainty/uncertainty duality.

F. The PLT Performance Bounds

Similarly to MIT and MLT, PLT has been found to have two performance bounds for system designs. The first is the lower performance bound for mover-coder designs, which is called mover-ectropy with symbol A and values given in SI second units for the motion life-time interval that it represents. A mover-coder is any replacement of the original signal-mover of physical signals that is lossless when it moves the same physical signals moved by the original signal-mover and

lossy when it does not. Examples of mover-coders are four-wheeled vehicles used in the space-dislocation of people and photons that carry electromagnetic radiation at the speed of light in a vacuum. An example of a lossy mover-coder is an automobile that can only move six people, but yet replaces a van that carries ten people, thus the four people left behind represent a physical signal loss. Similar to the processor-entropy K , the mover-entropy A is a minimax criterion that can be conveniently illustrated with a computational device contained in a sphere. The computations start on one side of the sphere and end on the other side with a constant speed v of travel along all possible connecting paths. As a mover moves along one of these connecting paths at constant speed v binary operations are performed in cascade. A is then

$$A = \pi r / v \quad (6)$$

where r is the radius of the sphere. To derive this result it is first noted that $\pi r / v$ is the minimum life-time for computations that are restricted to the surface of the sphere. On the other hand, $2r / v$ is the minimum life-time for computations that are not restricted as to which path may be taken. Notice that this minimum life-time path is along the diameter of the sphere whose distance is $2r$. The largest of these two life-times, i.e. $\pi r / v$, is then the minimax mover-entropy A . Thus A is defined

$$A = \max[L_M(\gamma_1), \dots, L_M(\gamma_N)] = \max[f_1[C_M(\gamma_1)], \dots, f_N[C_M(\gamma_N)]] \quad (7)$$

where: a) $\gamma = [\gamma_1, \dots, \gamma_N]$ is the N -dimensional signal-mover vector output; b) $L_M(\gamma_i)$ is the γ_i mover-latency, e.g. $L_M(\text{surface path}) = \pi r / v$ (where $v=c$ for photon); and c) $f_i[C_M(\gamma_i)] = L_M(\gamma_i)$ conveys $L_M(\gamma_i)$ dependence on γ_i mover-constraint $C_M(\gamma_i)$.

The second and upper PLT performance bound is for channel and mover (CMI) coder designs, see Fig. 2b and [1], [6]. The c shown in Fig. 2b reminds us about the upper speed of light in a vacuum limit conjectured by Einstein that movers can never exceed. While the CMI-coder's mover-coder efficiently compresses life-time, its channel-coder efficiently uses overhead life-time for the space-communication of life-time through a multi-path life-time channel. The CMI-coder's bound is called channel-stay with symbol T and denotes the maximum percentage of the physical latency extracted without loss through a multi-path life-time channel. T is defined by

$$0 \leq T = (A_{\underline{\varepsilon}} - A_{\underline{\varepsilon}/\underline{\phi}}) / A_{\underline{\varepsilon}} \leq 1 \quad (8)$$

where: 1) $\underline{\varepsilon}$ and $\underline{\phi}$ are N -dimensional vectors that are the input and output, respectively, of a multi-path life-time channel; and 2) the conditional mover-entropy $A_{\underline{\varepsilon}/\underline{\phi}}$ is a *channel-induced life-time penalty* whose value determines the percentage of the life-time that can be space-communicated without loss. For instance, if a computational sphere yields 1.2 msec for its minimum surface path and 1 msec for its direct diameter path, $A_{\underline{\varepsilon}} = 1.2$ msec. Then if the computations of each path are slowed down by a life-time channel that increases the computation life-time by at most 0.2 msec, it follows that $A_{\underline{\varepsilon}/\underline{\phi}} = 0.2$ msec. In turn, this results in $T = (1.2 - 0.2) / 1.2 = 0.834$ informing us that only 83.3% of the 1.2 msec life-time in $A_{\underline{\varepsilon}}$ can be space-communicated without loss. Thus the spherical computer life-time must be of at least 1.4 msecs.

G. The PIT Performance Bounds

Similarly to MIT, MLT and PLT, PIT has been found to have two performance bounds for system designs [1], [6]. The first is the lower performance bound for retainer-coder designs, which is called retainer-entropy with symbol N and values given in SI square meter units for the retention life-space surface area that it represents. A retainer-coder is any replacement of the original signal-retainer of physical signals that is lossless when it retains the same physical signals of the original signal-retainer and lossy when it does not. Examples of retainer-coders are a thermos used in the time-dislocation of hot tea and an atom that retains its spin direction. An example of a lossy retainer-coder is a thermos that can only store three hot tea servings, but yet replaces a thermos that stores five hot tea servings, thus the two hot tea servings left behind represent a physical signal loss. Similarly to the source-entropy H , the retainer-entropy N is an expectation criterion. N is the expected retainer-information

$$N = E[I_R(\underline{\varepsilon}_i)] = \sum_{i=1}^{\Omega} I_R(\underline{\varepsilon}_i) P_R(\underline{\varepsilon}_i) = 4\pi r^2 \quad (9)$$

$$I_R(\underline{\varepsilon}_i) = 4\pi r_i^2 (P_R(\underline{\varepsilon}_i)), \quad r = \sqrt{\sum_{i=1}^{\Omega} r_i^2 (P_R(\underline{\varepsilon}_i) P_R(\underline{\varepsilon}_i))} \quad (10)$$

where: 1) $\underline{\Psi} \in \{\underline{\varepsilon}_1, \dots, \underline{\varepsilon}_{\Omega}\}$ is a n -dimensional random vector composed of Ω vector outcomes (or microstates) $\{\underline{\varepsilon}_1, \dots, \underline{\varepsilon}_{\Omega}\}$; 2) $I_R(\underline{\varepsilon}_i)$ is the $\underline{\varepsilon}_i$ retainer-information in square meter units, which specifies the minimum surface area of a sphere of radius $r_i(\cdot)$ that satisfies the volume V_i of $\underline{\varepsilon}_i$; 3) $P_R(\underline{\varepsilon}_i)$ is the $\underline{\varepsilon}_i$ retainer-probability; and 4) r is the radius of the sphere given by the square root of the expected square radius of microstates specified with minimum surface area spheres. An example of a lossless retainer-coder that achieves the retainer-entropy $N = 4\pi r^2$ is a spherical thermos of hot tea whose volume is the same as that of the original cylindrical thermos.

The second and upper PIT performance bound is for sensor and retainer integrated (SRI) coder designs, see Fig. 2c and [1], [6]. The χ shown in Fig. 2c reminds us about the upper pace (the retention dual of motion speed in SI sec/m^3 units) of dark (the retention dual of light) in an uncharged and non-rotating black hole (UNBH) (the retention dual of a vacuum) limit that was first derived in 2008 [16] for retainers. The expression and value for the pace of dark in an UNBH are

$$\chi = \tau / V = 960\pi c^2 / hG = 6.1123 \times 10^{63} \text{ secs}/m^3 \quad (11)$$

where τ is the life expectancy (or duration) of a UNBH with initial volume V , and h and G are the Plank and gravitational constants, respectively. While the SRI-coder's retainer-coder efficiently compresses life-space, its sensor-coder efficiently uses overhead life-space for the time-observation of life-space across a noisy life-space sensor. The SRI-coder's bound is called sensor-scope with symbol I and denotes the maximum percentage of the physical information extracted without loss across a noisy life-space sensor. I is defined by

$$0 \leq I = (N_{\underline{\Xi}} - N_{\underline{\Xi}/\underline{\Phi}}) / N_{\underline{\Xi}} \leq 1 \quad (12)$$

where: 1) $\underline{\Xi}$ and $\underline{\Phi}$ are n -dimensional vectors that are the input and output, respectively, of a noisy life-space sensor; and 2) the conditional retainer-entropy $N_{\underline{\Xi}/\underline{\Phi}}$ is a *sensor-induced life-space penalty* whose value determines the percentage of the life-space that can be time-observed without loss. For

instance, if a cylindrical thermos for hot tea with a surface area of $168\pi \text{ cm}^2$ has a retainer-entropy of $N_{\Xi}=144\pi \text{ cm}^2$, this retainer-entropy can be implemented with a spherical thermos with a 6 cm radius that has the same volume as the original cylindrical thermos. However, if the hot tea is time-observed with a noisy life-space sensor consisting of random people that require the drinking of the hot tea from a thermos cup with a $166\pi \text{ cm}^2$ surface space, the sensor-induced life-space penalty will be of $22\pi \text{ cm}^2$, i.e. $N_{\Xi/\Phi}=22\pi \text{ cm}^2$. In turn, this results in $I=(144-22)/144=0.847$ informing us that only 84.7% of the $144\pi \text{ cm}^2$ life-space of N_{Ξ} can be time-observed without loss. Thus the hot tea life-space must be of at least $166\pi \text{ cm}^2$.

III. THE BRIDGES OF STATISTICAL PHYSICS

In this section it is shown that statistical physics, of which thermodynamics is a special case, offers a natural link between the four LIT quadrants. First a simple relation is noted between the Boltzmann thermodynamics-entropy S and the Shannon source-entropy H [3], i.e.,

$$S = \ln 2 kH \quad (13)$$

where S and k , the Boltzmann constant, are given in SI joules per kelvin units and H indicates the expected source-information in bits of the microstates (1). Moreover, when the microstates are equally likely H attains the maximum value of $H=\log_2 \Omega$ and $S=k\ln \Omega$ as expected. The thermodynamics-entropy of an uncharged nonrotating black hole (UNBH) has been investigated by Hawking and others [3]-[4], the author inclusive starting in 2008 [16]. The UNBH's thermodynamics-entropy can be expressed as follows

$$S_{EH} / \ln 2 k = \pi^3 A / 2 \ln 2 hG = \chi c A / 1920 \ln 2 = H_{EH} = N_{EH} / N_{Bit} \quad (14)$$

where: 1) EH signifies the 'event horizon' where a black-hole meets a vacuum and photon pairs are spontaneously created with one photon emerging inside the vacuum and the other emerging inside the black-hole. While the photon inside the vacuum increases the positive energy of the vacuum, the photon inside the black-hole decreases the positive energy of the black-hole; 2) A is the surface area of the spherical UNBH; 3) S_{EH} , H_{EH} and N_{EH} are the thermodynamics-entropy, source-entropy and retainer-entropy of the UNBH, respectively, with

$$N_{EH} = A = 4\pi r^2 = 4\pi(2GM_{EH} / c^2)^2 \quad (15)$$

and M_{EH} being the UNBH mass; and 4) N_{Bit} is defined by

$$N_{Bit} = 2 \ln 2 hG / \pi c^3 = 4\pi r_{Bit}^2 = 4\pi(2GM_{Bit} / c^2)^2 \quad (16)$$

$$\pi r_{Bit} = \sqrt{\pi \ln 2} l_p = 1.4757 l_p, \quad l_p = \sqrt{hG / 2\pi c^3} \quad (17)$$

$$M_{bit} = \sqrt{2 \ln 2} M_{RP} = 1.1774 M_{RP}, \quad M_{RP} = \sqrt{hc / 16\pi^2 G} \quad (18)$$

and denotes the retainer-entropy of a bit that is given by the surface area of a sphere where $1/2$ of its circumference πr_{Bit} (r_{Bit} is the radius of the sphere) is larger than the Plank length l_p as seen from (17) and expected by theory [3]. Moreover, a bit has a mass M_{Bit} (or energy for photons) with escape speed close to c (c for photons) exceeding the reduced Plank mass M_{RP} (18).

From (14) it is noted that statistical physics produces a inherent link between MIT's source-entropy H_{EH} and PIT's retainer-entropy N_{EH} . Unfortunately, however, the simple linear relation $H_{EH}=N_{EH}/N_{Bit}$ only applies to a UNBH and thus must be found for other cases. For instance, for an ideal gas

(IG) [17]-[18] the following nonlinear bridge between its retainer-entropy N_{IG} and source-entropy H_{IG} can be derived

$$S_{IG} / \ln 2 k = H_{IG} = J(\ln VT^{c_V} / JB + c_p) / \ln 2 = J \log_2(N_{IG} / \Delta N_{IG}) \quad (19)$$

$$N_{IG} = 3V / r = 4\pi r^2 = 4\pi(2GM / v_e^2)^2, \quad \Delta N_{IG} = 1 / \phi_s = 4\pi \Delta r^2 = 4\pi(2G\Delta M / v_e^2)^2 \quad (20)$$

$$\phi_s = \sigma(eM_M / N_A)^{5/2} (2\pi kT / h^2)^{3/2} (r / M) / 3 \quad (21)$$

$$\sigma = g e^{c_p-5/2} T^{c_V-3/2}, \quad M_M = M N_A / J = 3kTN_A / v_{rms}^2, \quad r / M = 2G / v_e^2 \quad (22)$$

where: 1) J is the number of gas molecules; 2) V , T , and M are the volume, temperature and mass of the gas in SI units; 3) c_V and $c_p=c_V+1$ are the dimensionless heat capacity constants under constant volume and pressure conditions, respectively, with $c_V=3/2$ and $c_p=5/2$ for a monatomic gas (the value of c_V can be found either experimentally or theoretically, from the degrees of freedom d_f of the molecules where $c_V=d_f/2$); 4) h is the Plank constant; 5) r is the radius of a sphere of volume V ; 6) v_e is the escape speed in SI m/sec units from the gravitational field of M (assumed a point mass at the center of the sphere); 7) v_{rms} is the root mean square speed of the gas molecules; 8) M_M is the molar mass of the molecules; 9) N_A is Avogadro's number; j) $B = T^{3/2} X^3 / g$ is an undetermined gas constant where $X = h / \sqrt{2\pi M_M kT / N_A}$ is the thermal de Broglie wavelength and $g=1$ for a monatomic gas; 10) ϕ_s in weavelength (the retention dual of wavelength [16]) cycles/ m^2 units is the surface fix (the retention dual of frequency [16]) of the gas; 11) σ is a dimensionless constant that has a value of one for a monatomic gas ($c_V=3/2$) and is more than one otherwise; and 12) ΔN_{IG} is the part of the retainer-entropy N_{IG} associated with ΔM ($\Delta M \ll M$) whose molecules' escape speed is $v_e = \sqrt{2GM / r}$ (20). Thus from (19) it is noted that the general relationship between N and H is nonlinear, i.e.

$$S / \ln 2 k = H = f(N) \quad (23)$$

where $f(\cdot)$ is some function of N .

A. Lingerdynamics, the Certainty Dual of Thermodynamics

It is possible to conjecture that the information-uncertainty thermodynamics bridge from N to H (23) has a latency-certainty dual. This latency-certainty dual I have called lingerdynamics. Thus in essence statistical physics is said to have a certainty/uncertainty duality. In addition to providing a bridge between A and K , lingerdynamics can also be bridged with thermodynamics to yield

$$Z = K = g(A) \quad (24)$$

$$Z = \sqrt{S / \ln 2 k} \quad (25)$$

$$K = \sqrt{H} \quad (26)$$

$$A = \sqrt{\pi N / 4v_e^2} \quad (27)$$

where: 1) Eq. (24) is the certainty dual of (23); 2) Z is a dimensionless lingerdynamic-entropy that is the dual of $S/\ln 2k$ where (25) is the bridge from S to Z (note from (24) that Z is the same as the processor-entropy K); 3) Eq. (26) relates the bits of H to the bors of K (or Z); 4) Eq. (27) relates $N=4\pi r^2$ of (9) to the mover-entropy $A=\pi r/v_e$ of (6) for a computational sphere where the movers are assumed to be particles (or photons) moving at the escape speed $v_e \leq c$ where $v_e=c$ for a UNBH; and 5) $g(\cdot)$ is some function of A . Moreover,

$$A_{\text{Bor}} = \sqrt{\pi N_{\text{Bit}} / 4c^2} \quad (28)$$

relates A_{Bor} of the N_{Bit} 's sphere to N_{Bit} to yield the bor entropy

$$A_{\text{Bor}} = \pi r_{\text{Bit}} / c = \sqrt{\pi \ln 2} T_p = 1.4757 T_p, \quad T_p = l_p / c \quad (29)$$

which is found to be larger than the Plank time T_p as expected by theory. Similarly the relationship

$$\Delta A_{\text{IG}} = \sqrt{\pi \Delta N_{\text{IG}} / 4v_e^2} \quad (30)$$

relates ΔA_{IG} of the ΔN_{IG} 's sphere to ΔN_{IG} .

Using the above bridges one obtains for a UNBH

$$S_{\text{EH}} / \ln 2k = H_{\text{EH}} = N_{\text{EH}} / N_{\text{Bit}} = (A_{\text{EH}} / A_{\text{Bor}})^2 = K_{\text{EH}}^2 = Z_{\text{EH}}^2 \quad (31)$$

and for an ideal gas

$$S_{\text{IG}} / \ln 2k = H_{\text{IG}} = J \log_2(N_{\text{IG}} / \Delta N_{\text{IG}}) = J \log_2(A_{\text{IG}} / \Delta A_{\text{IG}})^2 = K_{\text{IG}}^2 = Z_{\text{IG}}^2 \quad (32)$$

The defining expressions for the variables of (31) and (32) given earlier can also be expressed in terms of the physical retention duals of motion variables [16] as well as the linderdynamics dual for temperature called lingerature. When this is done the following expressions result:

$$N_{\text{Bit}} = 4 \ln 2 l_p^2 = 1920 \ln 2 / c\chi \quad (33)$$

$$l_p = \sqrt{480 / c\chi} \quad (34)$$

$$S_{\text{EH}} = k N_{\text{EH}} / 4l_p^2 = kc\chi N_{\text{EH}} / 1920 \quad (35)$$

$$\Delta N_{\text{IG}} = 1 / \phi_s = 4\pi(2G\Delta M / v_e^2)^2 = 4\pi(3/4\pi\chi)^{2/3}(6\Phi\Delta O / \Pi_e^2)^2 \quad (36)$$

$$\tau = 4\pi r^3 \chi / 3 \quad (37)$$

$$\alpha = \Phi O / \tau^{4/3} = GM\chi / 4\pi r^4 c^2 = a\chi / 4\pi^2 c^2 \quad (38)$$

$$\Phi = \sqrt[3]{4\pi\chi^{10} / 81c^{12}} G = 1.8538 \times 10^{168} \text{ Pa}\cdot\text{sec}^{4/3} / \text{kg}_R^2 \quad (39)$$

$$\Delta O = \Delta M c^2 / \chi \quad (40)$$

$$\Pi_e = \sqrt{6\Phi O / \tau^{1/3}} = \sqrt{2GM / r} \chi / c = v_e \chi / c \quad (41)$$

$$\phi_s = \sigma(eO_M \chi / c^2 N_A)^{5/2} (2\pi \frac{\chi}{h^2})^{3/2} \sqrt[3]{3c^6 / 4\pi\chi^4} (\tau^{1/3} / O) \sqrt[3]{3} \quad (42)$$

$$O_M = M_M c^2 / \chi \quad (43)$$

$$\frac{\chi}{T} = kT \chi \quad (44)$$

$$\Pi_{\text{rms}} = \sqrt{3 \frac{\chi}{T} N_A / O_M} = \sqrt{3kT N_A / M_M} \chi / c = v_{\text{rms}} \chi / c \quad (45)$$

where: 1) Eqs. (40), (41), (43), (44) and (45) are statistical bridges from ΔM , v_e , M_M , T and v_{rms} to the mater ΔO in SI $\text{kg}_R = \text{kg}\cdot\text{m}^5/\text{sec}^3$ (the retention dual of mass ΔM), escape pace Π_e in SI sec/m^3 , molar mater O_M , lingerature χ in SI $\text{Pa}\cdot\text{sec}$, and rms pace Π_{rms} in SI sec/m^3 ; 2) Eq. (37) is the bridge from the radius r of a sphere in the vacuum of a point-mass M in motion-space, to retention τ in the UNBH of a point-mater in retention-time [16]; 3) α is the *escalation* of mater (the retention dual of the acceleration 'a' of mass) in SI sec/m^6 ; 4) Eq. (38) is the bridge from a , that is due to the gravitational-field of a point-mass M space-dislocated by r , to α , that is due to the gravidness-fallow (the dual of the gravitational-field) of a point-mater O time-dislocated by τ ; 5) Φ is the gravidness constant; 6) Eq. (39) is the bridge from G to Φ ; 7) Eqs. (36) and (42) are retention duals for (20) and (21); and 8) Eqs. (33)-(35) express S_{EH} , N_{Bit} and l_p in terms of $c\chi$ that is in SI reciprocal m^2 units. In Table 1 additional thermodynamics and linderdynamics concepts, bridges and related variables [8] are stated. Of special note are the displayed laws of thermodynamics that drive the Universe [18] and its linderdynamics certainty duals where the 0th and 3th laws are not shown in this table. In other papers these dualities,

Table 1 Selected Statistical Physics Terms and Dualities

Thermodynamics (About Work and Heat Transfer)	Bridge	Ligerdynamics (About Effort and Hover Transfer)
Motion-Time t in SI sec		Retention-Space ξ in SI m^3
Motion-Space $r(t)$ in SI m		Retention-Time $\tau(\xi)$ in SI sec
Space-Dislocation Δr in SI m		Time- Dislocation $\Delta \tau$ in SI sec
Life-Time Δt in SI sec		Life-Space $\Delta \xi$ in SI m^3
Mass M in SI kg	$O = Mc^2 / \chi$	Mater O in SI $\text{kg}_R = \text{kg}\cdot\text{m}^5/\text{sec}^3$
Speed $v = \Delta r / \Delta t$ in SI m/sec	$I = v\chi / c$	Pace $I = \Delta \tau / \Delta \xi$ in SI sec/ m^3
Momentum $p = Mv$ in SI kg.m/sec	$\nu = pc$	Endurance $\nu = O/I$ in SI Joule
Avg. Force $f = \Delta p / \Delta t$ in SI N	$\gamma = f\nu\chi$	Avg. Press $\gamma = \Delta \nu / \Delta \xi$ in SI Pa
Mass-Energy $E = Mc^2$ in SI J	$\varpi = E\chi$	Mater-Viscosity $\varpi = O\chi^2$ in SI Pa.sec
Work Win SI J	$\Psi = W\chi$	Effort Ψ in SI Pa.sec
Heat Q in SI J	$\Lambda = Q\chi$	Hover Λ in SI Pa.sec
D-less Thermodynamics-Entropy $S / \ln 2k = H$ is Dimensionless	$Z = \sqrt{S} / \ln 2k$	D-less Ligerdynamics-Ectropy $Z = K$ is Dimensionless
The Thermodynamics Gas Law $PV = J$ in SI J	$\gamma\tau = PV\chi$	The Ligerdynamics Gas Law $\gamma\tau = J$ in SI Pa.sec
Energy-Temperature in SI J $\frac{1}{kT} = k(\partial S / \partial U)^{-1} = (\partial U / \partial H) / \ln 2$	$\frac{\chi}{T} = \frac{\chi}{T}\chi$	Viscosity-Lingerature in SI Pa.sec $\frac{\chi}{T} = (\partial \varpi / \partial Z^2) / \ln 2 = (\partial \varpi / \partial K^2) / \ln 2$
Internal Energy $U = c_v J$	$\Theta = U\chi$	Internal Viscosity $\Theta = c_v J\chi$
Heat Capacity Constants c_v and c_p	$c_v = c_v$ and $c_p = c_p$	Hover Capacity Constants c_v and c_p
Enthalpy Heat $H = U + PV$	$\Xi = H\chi$	Ecthalpy Hover $\Xi = \Theta + \gamma\tau$
Helmholtz Work $A = U - ST = U - \ln 2H$	$\Gamma = A\chi$	Helmholtz Effort $\Gamma = \Theta - \ln 2Z^2 = \Xi - \ln 2K^2$
Gibbs Work $G = H - ST = H - \ln 2H$	$Y = G\chi$	Gibbs Effort $Y = \Xi - \ln 2Z^2 = \Xi - \ln 2K^2$
The 1 st Law of Thermodynamics (Conservation of Energy) $\Delta U = \Delta Q - \Delta W$	$\Delta\Theta = \Delta U\chi$	The 1 st Law of Ligerdynamics (Conservation of Viscidity) $\Delta\Theta = \Delta\Lambda - \Delta\Psi$
The 2 nd Law of Thermodynamics (Non-Conservation of Entropy) $\partial S = \partial Q / T = k \ln 2H \geq 0$	$\partial Z = \sqrt{\partial S} / \ln 2k$	The 2 nd Law of Ligerdynamics (Non-Conservation of Ectropy) $\ln 2\partial Z^2 = \partial\Lambda / \partial K^2 \geq 0$
PV Diagram and its Cycles		$\gamma\tau$ Diagram and its Cycles
Wavelength λ in SI m		Weavelength l in SI sec
Frequency f in SI λ cycles/sec		Surface Fix ϕ_s in l cycles/ m^2
Wave Speed $v = \lambda f$		Weave Surface Pace $I_s = l\phi_s$
Spontaneous Heat Engines $\frac{\chi}{T}_{\text{High}} \rightarrow \frac{\chi}{T}_{\text{Low}}$		Spontaneous Hover Engines $\frac{\chi}{T}_{\text{High}} \rightarrow \frac{\chi}{T}_{\text{Low}}$
Non-Spontaneous Work Engines $\frac{\chi}{T}_{\text{High}} \leftarrow \frac{\chi}{T}_{\text{Low}}$		Non-Spontaneous Effort Engines $\frac{\chi}{T}_{\text{High}} \leftarrow \frac{\chi}{T}_{\text{Low}}$
Carnot Heat Engine Max. Eff. $(\frac{\chi}{T}_{\text{High}} - \frac{\chi}{T}_{\text{Low}}) / \frac{\chi}{T}_{\text{High}}$		Carnot Hover Engine Max. Eff. $(\frac{\chi}{T}_{\text{High}} - \frac{\chi}{T}_{\text{Low}}) / \frac{\chi}{T}_{\text{High}}$

inclusive of the certainty dual of work and heat, i.e., effort and hover, respectively, are treated, e.g., see [8].

B. An Illustrative Biochemistry Example

It is expected that the novel bridge expression (32) will find applications in many fields. An interesting case that is discussed next is the *conjecture* that (32) can be used to study the life expectancy of biological systems. Since human life expectancy and macroscopic parameters are relatively well known, a preliminary study will be pursued for this case. For instance, the maximum human lifespan is known to be longer than 120 years where the longest unambiguously documented lifespan is that of 122 years and 164 days by Jeanne Calment of France (1875-1997). It is also well known that our cells are made mostly of water H_2O molecules with a molar mass of 18.0151 g/mol. Furthermore, the internal temperature of our bodies is of approximately 310 K. Using these last two macroscopic parameters and an assumed lifespan it will be

shown that (32) predicts a daily caloric intake that correlates well with the expected results.

The development begins by using Clausius' definition of thermodynamics-entropy to model the daily digestion of food of mass ΔM with the expression

$$\Delta S_{\text{Dig}} = \Delta Q / T_{\text{Dig}} = C_1 C_2 \Delta M / T_{\text{Dig}} \text{ in SI } J/K \text{ units} \quad (46)$$

where ΔQ denotes the heat energy in J units of the digested food, T_{Dig} is the temperature of digestion, $C_1 = 4.2 \text{ J/cal}$ and $C_2 = 5,000 \text{ kcal/kg}$. On the other hand, it is assumed that a matching or similar amount of mass ΔM is exhaled daily by the human body in the form of a gas. Linked to this exhale that maintains the body mass M and volume V unaltered from day to day, is the Boltzmann thermodynamic-entropy $\Delta S_{\text{Exh}} = S_f - S_i$ where S_i is the entropy when the day begins and $S_f > S_i$ is when it ends. From (32) it is noted that ΔS_{Exh} is given by

$$\Delta S_{\text{Exh}} = S_f - S_i = k(J_i + \Delta J) \ln(N_{\text{IG},f} / \Delta N_{\text{IG}}) - kJ_i \ln(N_{\text{IG},i} / \Delta N_{\text{IG}}) \Big|_{N_{\text{IG},f} = N_{\text{IG},i} = N_{\text{IG}}} \\ = k\Delta J \ln(N_{\text{IG}} / \Delta N_{\text{IG}}) = 3V / r \Delta N_{\text{IG}} = \tau / (r \Delta N_{\text{IG}} \Pi / 3) \quad (47)$$

$$N_{\text{IG}} = 4\pi r^2 = 4\pi(2GM / v_e^2)^2 \quad (48)$$

$$\Delta N_{\text{IG}} = 1 / \phi_s = 4\pi \Delta r^2 = 4\pi(2G\Delta M / v_e^2)^2 \quad (49)$$

$$\phi_s = \sigma(eM_M / N_A)^{5/2} (2\pi kT_{\text{Exh}} / h^2)^{3/2} (r/M)^{1/3}, \sigma = g e^{c_p - 5/2} T_{\text{Exh}}^{c_v - 3/2} \quad (50)$$

$$M_M / N_A = M / J = 3kT / v_{\text{rms}}^2, \quad r / M = 2G / v_e^2 \quad (51)$$

$$c_v = d_f / 2 \text{ and } c_p = c_v + 1 \quad (52)$$

$$V = \tau / \Pi = 4\pi r^3 / 3 = M / 1000 \quad (53)$$

where: 1) τ and Π in (47) and (53) denote a lifespan in secs and retention pace in sec/m^3 , respectively; 2) the term $r \Delta N_{\text{IG}} \Pi / 3$ in (47) corresponds to the M time-dislocation, or weavelength $l = r \Delta N_{\text{IG}} \Pi / 3 = 86,400$ seconds for a single day; 3) J signifies the number of H_2O molecules that make up M ; 4) ΔJ denotes the number of unknown particles forming ΔM ; 5) Eq. (53) assumes that the human mass density is that of liquid water, thus, for instance, if $M = 70 \text{ kg}$ (154.3 lbs) then $V = 0.07 \text{ m}^3$ and $r = 0.2557 \text{ m}$; and 6) T_{Exh} is the exhale temperature. When (46) and (47) are equated it follows that

$$21'000,000 \Delta M / T_{\text{Dig}} = k\Delta J \ln(N_{\text{IG}} / \Delta N_{\text{IG}}) = \tau / 86,400 = (M / \Delta M)^2. \quad (54)$$

Eqs. (47)-(54) can then be solved under different assumptions, e.g. when $M = 70 \text{ kg}$, $T_{\text{Dig}} = T_{\text{Exh}} = 310 \text{ K}$, $d_f = 16.1$ for H_2O at 310 K and $\tau = 130$ years (or 4.0997 Gsec) it is found that $\Delta M = 0.3214 \text{ kg}$ for a daily caloric intake of $C_2 \Delta M = 1,607 \text{ kcal}$ (other results derived from (54) are $C_2 \Delta M = 1,827 \text{ kcal}$ if $\tau = 100$ yrs, $C_2 \Delta M = 2,000 \text{ kcal}$ if $\tau = 83.4$ yrs, etc.). The remaining values for $\tau = 130$ years are: 1) $\sigma = 1.6672$; 2) $V = 0.07 \text{ m}^3$; 3) $r = 0.2557 \text{ m}$; 4) N_{IG} is 0.8412 m^2 ; 5) $\Delta N_{\text{IG}} = 1.7311 \times 10^{-5} \text{ m}^2$; 6) $J = 2.34 \times 10^{27}$ H_2O molecules; 7) $\Delta J = 1.4643 \times 10^{26}$ particles with an average molar mass of 1.3216 g/mol for ΔM (e.g. this molar mass is satisfied by $0.1736 \Delta M$ of carbon dioxide CO_2 , $0.0714 \Delta M$ of water H_2O and $0.755 \Delta M$ of hydrogen H atoms); 8) a particle escape speed of $v_e = 19.118 \text{ mm/sec}$; 9) a particle kinetic rms speed of $v_{\text{rms}} = 655.1496 \text{ m/sec}$; 10) a retention pace of $\Pi = 58.567 \text{ Gsec}/m^3$; 11) a surface fix of $\phi_s = 57.768 \text{ kcycles}/m^2$; and 12) a surface pace of $\Pi_s = \phi_s l = 4.9911 \text{ Gsec}/m^2$. Finally, it should be noted that the previous preliminary study can be readily extended via a multi-species version of (32) to more elaborate molecular models for M .

IV. CONCLUSIONS

This paper reviewed the mathematical-physical theory of communication-observation that is part of latency-information theory or LIT. LIT is expressed in a revolution whose problems fall into two mathematical-intelligence quadrants and two physical-life ones. Using a structural-physical certainty/uncertainty duality conjecture from controls, LIT exhibits design methodologies inherited in each case from classical mathematical information theory or MIT. The efficiency system design philosophy of LIT was illustrated with controls, adaptive radar, physics and biochemistry examples. Moreover, thermodynamics was noted to advance uncertainty bridges for LIT's MIT and PIT that further illuminate physics retention problems such as those of gases. Using LIT's conjectured structural-physical dualities, statistical physics was also discovered to have a certainty dual for thermodynamics called lingerdynamics that results in a complete LIT quadrants bridge. The paper ends with an illustration of the conjecture that the derived statistical physics bridge can be used to make reasonable predictions of the daily caloric intake of biological systems for an assumed lifespan.

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